



Mission Critical Metallica[®]

Elemental Effects on Nickel-Base Superalloy Powders

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Aeromat 2012
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Outline

- 1. Genesis of PM superalloy design**
2. Processing Constraints
3. Application Needs
4. Future Potential

Development of PM Disk Alloys

- 45 years ago, powder metal superalloys became forgeable
- PM disk alloys originated from blade alloys
- Original disk heat treatments intended to coarsen microstructure for high strength

3,519,503

FABRICATION METHOD FOR THE HIGH TEMPERATURE ALLOYS

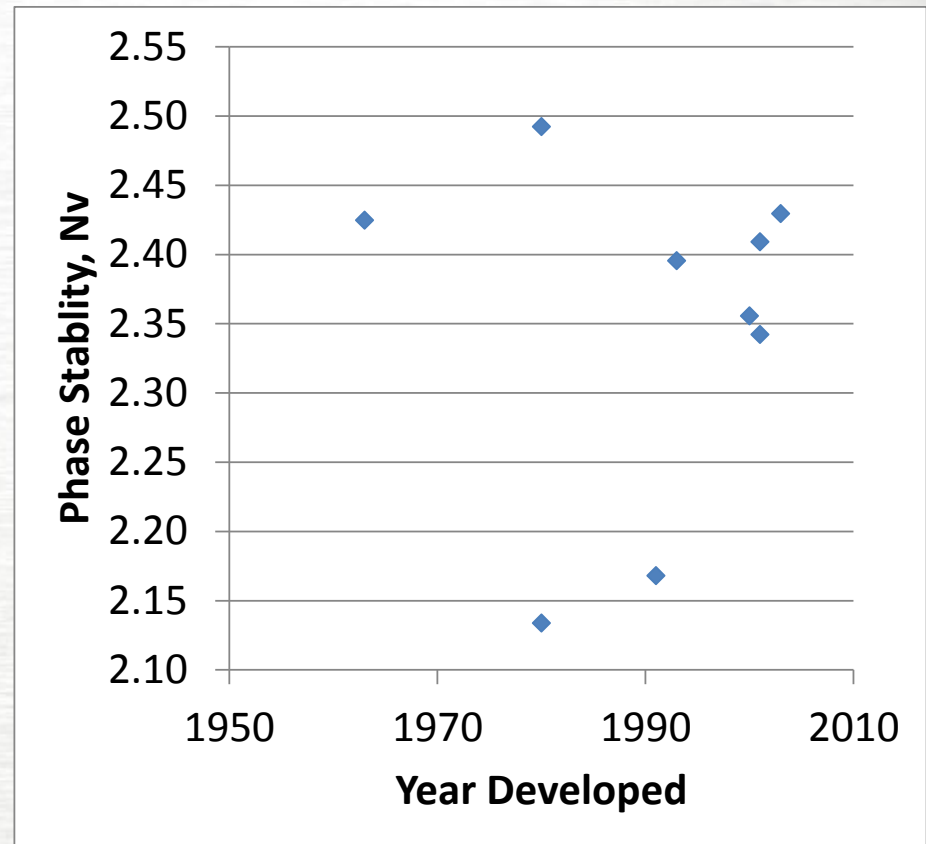
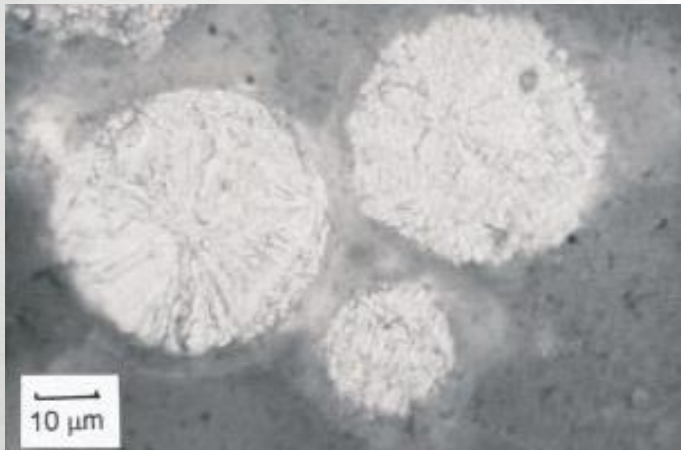
Joseph B. Moore, Jupiter Tequesta, and Roy L. Athey, North Palm Beach, Fla., assignors to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

No Drawing. Filed Dec. 22, 1967, Ser. No. 692,705

To restore the particular alloy to its normal condition of high strength and hardness subsequent to the forging operation, the conventional solution, stabilization, precipitation heat treatment is required. In the case of the IN100 alloy having a normal recrystallization temperature of about 2100F., the preferred heat treatment involves solution heat treatment at about 2175F. to produce grain growth which is followed by stabilization and precipitation heat treatment. The solution heat treat temperature of the various other alloys specifically mentioned herein are set forth in Table VIII.

PM Processing Provided Alloy Sandbox

Powder metal processing permitted the production of micro ingots capable of almost any composition



PM Alloys Utilize Small Area on Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H 1.0																	He 4.0
2	Li 6.9	Be 9.0											B 10.8	C 12.0	N 14.0	O 16.0	F 19.0	Ne 20.2
3	Na 23.0	Mg 24.3											Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5	Ar 39.9
4	K 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.8	Co 58.9	Ni 58.7	Cu 63.5	Zn 65.4	Ga 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9	Kr 83.8
5	Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Tc -98.0	Ru 101.1	Rh 102.9	Pd 106.4	Ag 107.9	Cd 112.4	In 114.8	Sn 118.7	Sb 121.8	Te 127.6	I 126.9	Xe 131.3
6	Cs 132.9	Ba 137.3	*	Hf 178.5	Ta 180.9	W 183.8	Re 186.2	Os 190.2	Ir 192.2	Pt 195.1	Au 197.0	Hg 200.6	Tl 204.4	Pb 207.2	Bi 209.0	Po -209.0	At -210.0	Rn -222.0
7	Fr -223.0	Ra -226.0	**	Rf -261.0	Db -262.0	Sg -263.0	Bh -262.0	Hs -265.0	Mt -266.0	Uun -269.0	Uuu -272.0	Uub -277.0						
			*	La 138.9	Ce 140.1	Pr 140.9	Nd 144.2	Pm -145.0	Sm 150.4	Eu 152.0	Gd 157.3	Tb 158.9	Dy 162.5	Ho 164.9	Er 167.3	Tm 168.9	Yb 173.0	Lu 175.0
			**	Ac -227.0	Th 232.0	Pa 231.0	U 238.0	Np -237.0	Pu -244.0	Am -243.0	Cm -247.0	Bk -247.0	Cf -251.0	Es -252.0	Fm -257.0	Md -258.0	No -259.0	Lr -262.0

• Gamma Prime Formers: Al, Ti, Ta, Nb

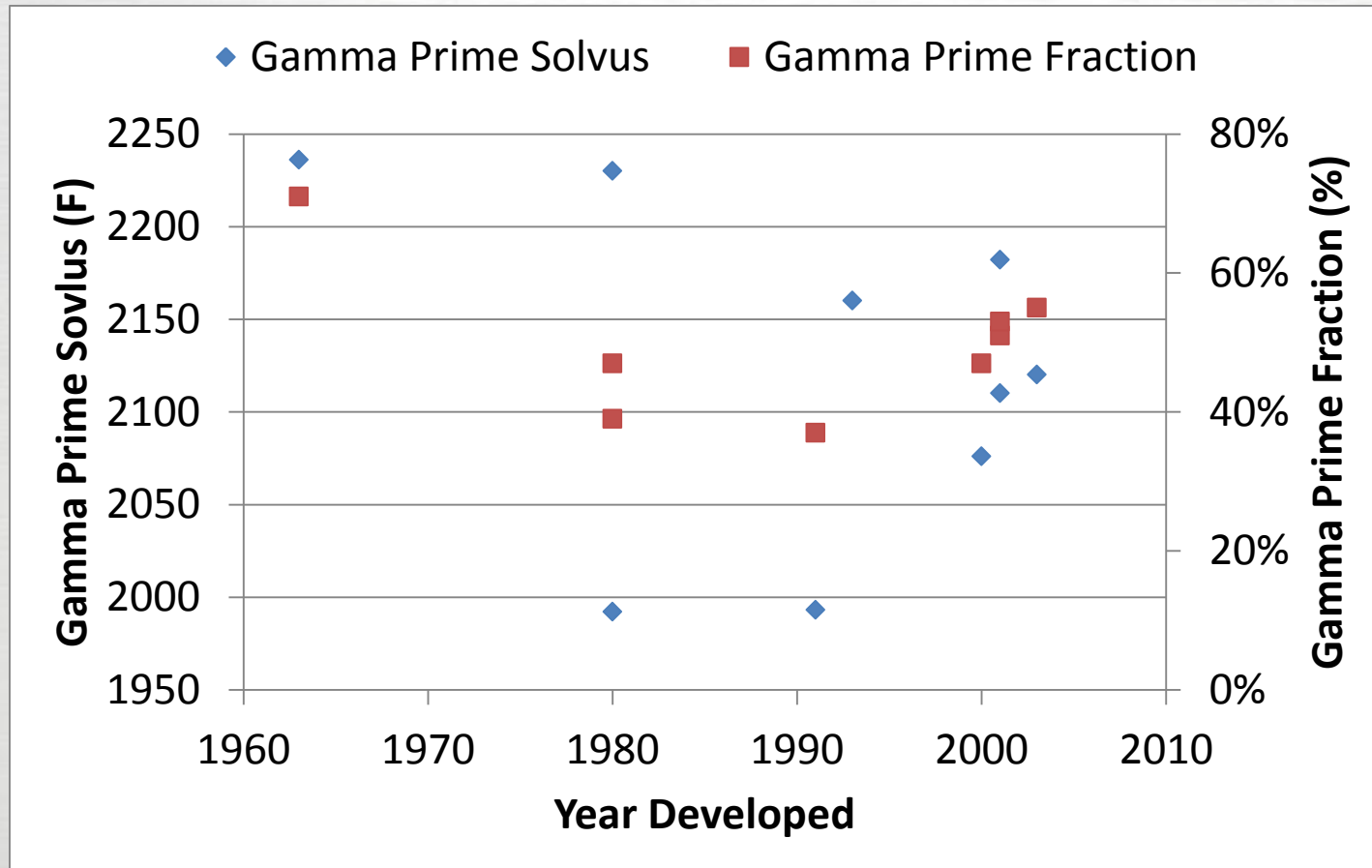
• Gamma Formers: Mo, W, Nb, (Ni)

• Oxidation Resistance: Cr

• Grain Boundary Conditioners: B, C, Hf, Zr

• From Pollock and Tin

High Gamma Prime Alloys



Modern Powder Metal Disk Alloys

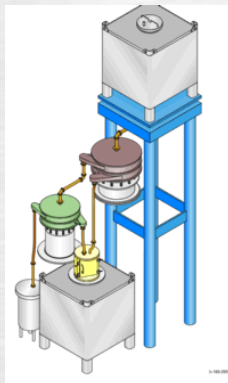
Wt Percent	Cr	Co	Ti	Al	Mo	C	V	B	Zr	Ni	Ta	W	Nb	Hf
IN100	10	15	4.7	5.5	3	0.17	0.95	0.015	0.05	61				
Rene 95	13	8	2.5	3.5	3.5	0.06		0.01	0.005	66		3.5		
MERL76	12.4	18.5	4.3	5	3.2	0.02		0.02	0.06	55			1.4	0.4
Rene 88	16	13	3.7	2.1	4	0.05		0.05	0.005	60			0.7	
N18	11.5	15.7	4.35	4.35	6.5	0.015		0.015	0.03	58				
R1000	15	18.5	3.6	3	5	0.017		0.05	0.06	52	2			0.5
ME-3	13.1	20	3.6	3.5	3.8	0.04		0.03	0.05	51	2.3	1.9	1.1	
Alloy 10	10.2	14.9	3.9	3.7	2.7	0.03		0.03	0.1	55	0.9	6.2	1.9	
LSHR	13	21	3.5	3.5	2.7	0.03		0.03	0.05	49	1.6	4.3	1.5	

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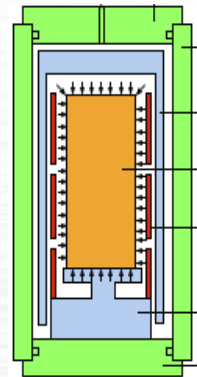
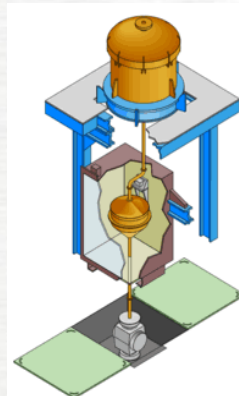
Powder to Parts Conversion Routes

Atomize



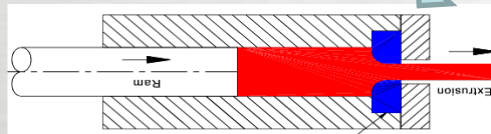
Screen

Fill

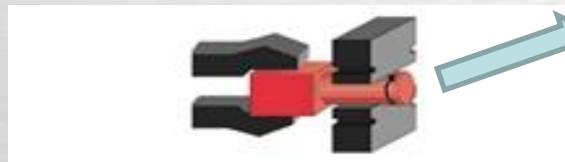


HIP

- HIP
- HIP and Press
- Extrude
- HIP and Extrude
- HIP and Forge



Extrude



Press

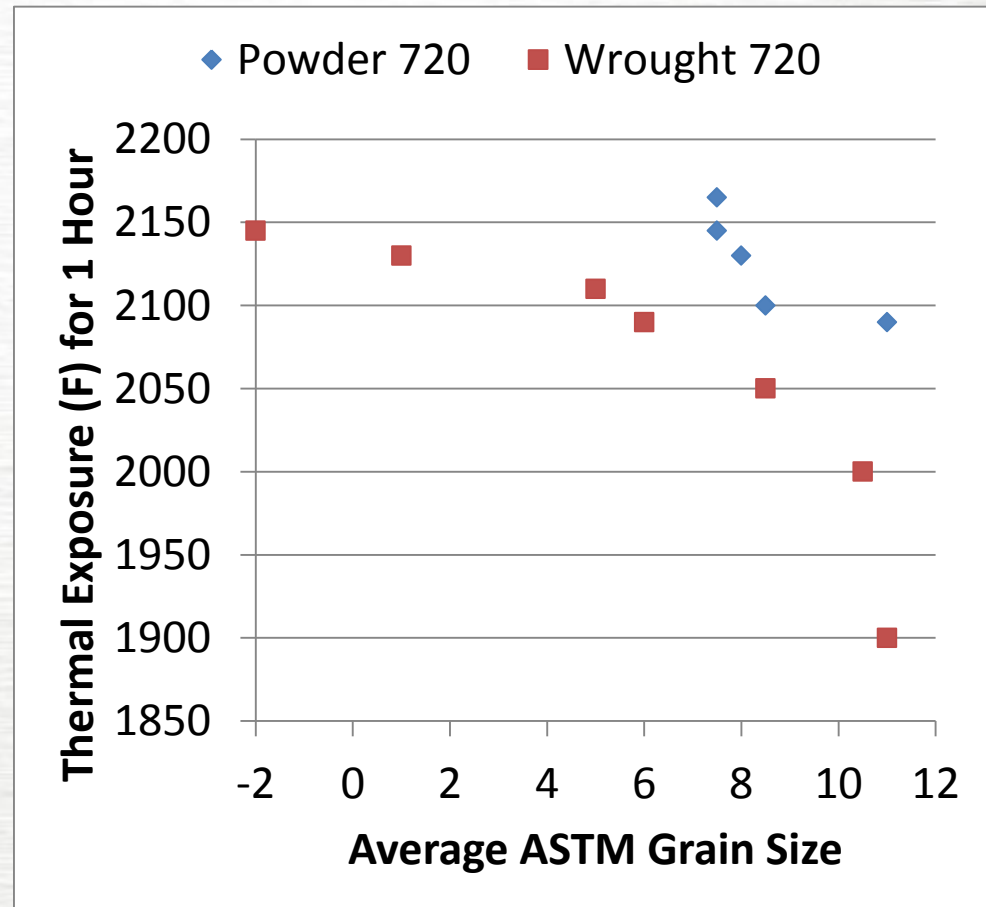


Isoforge



Constraining Grain Growth

- On heating for consolidation, Carbon and Boron can migrate to powder surfaces
- C / B / O particles serve as grain boundary constraints



Furrer JOM Jan 1999

Elemental Concerns with Powders

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
	1.0																	4.0
2	Li	Be											B	C	N	O	F	Ne
	6.9	9.0											10.8	12.0	14.0	16.0	19.0	20.2
3	Na	Mg											Al	Si	P	S	Cl	Ar
	23.0	24.3											27.0	28.1	31.0	32.1	35.5	39.9
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	39.1	40.1	45.0	47.9	50.9	52.0	54.9	55.8	58.9	58.7	63.5	65.4	69.7	72.6	74.9	79.0	79.9	83.8
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	85.5	87.6	88.9	91.2	92.9	95.9	-98.0	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	131.3
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	132.9	137.3		178.5	180.9	183.8	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	-209.0	-210.0	-222.0
7	Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
	-223.0	-226.0		-261.0	-262.0	-263.0	-262.0	-265.0	-266.0	-269.0	-272.0	-277.0						
			*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				138.9	140.1	140.9	144.2	-145.0	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.0	175.0
			**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
				-227.0	232.0	231.0	238.0	-237.0	-244.0	-243.0	-247.0	-247.0	-251.0	-252.0	-257.0	-258.0	-259.0	-262.0

- Gamma Prime Formers:

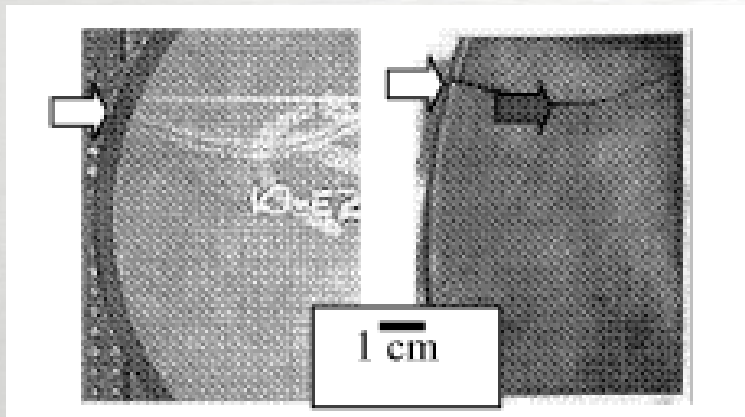
- Gamma Formers: Re

- Oxidation Resistance: Y, La

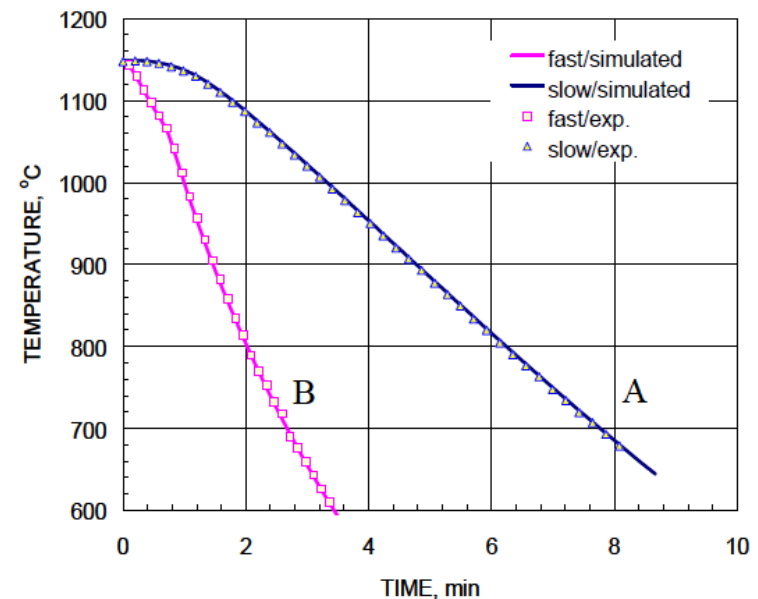
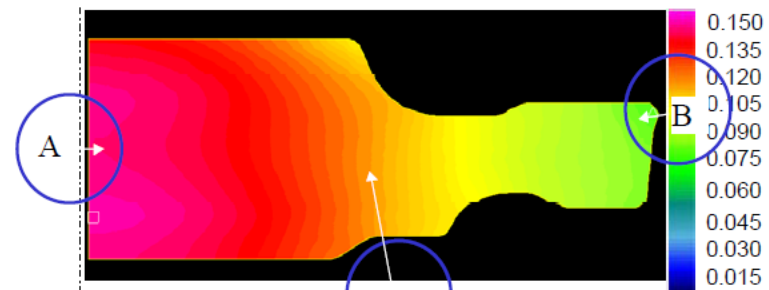
- Grain Boundary Conditioners: N

Precipitate Nucleation and Growth

As part of advanced powder compositional studies, heat treatment plays a critical role

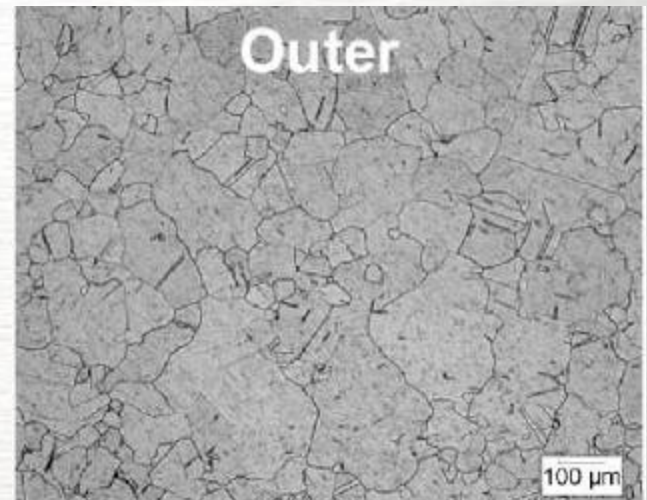
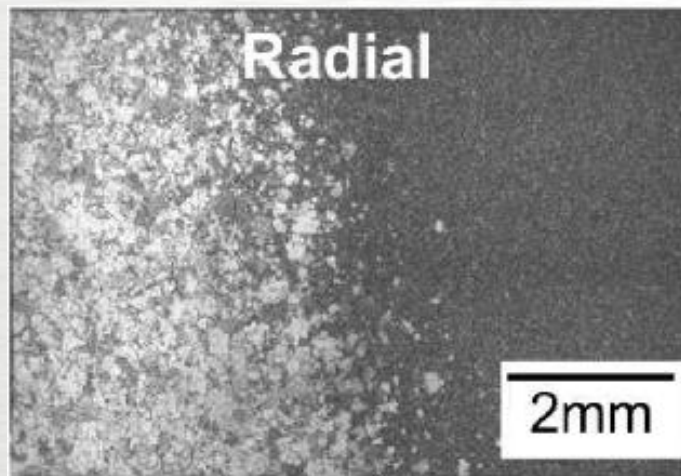
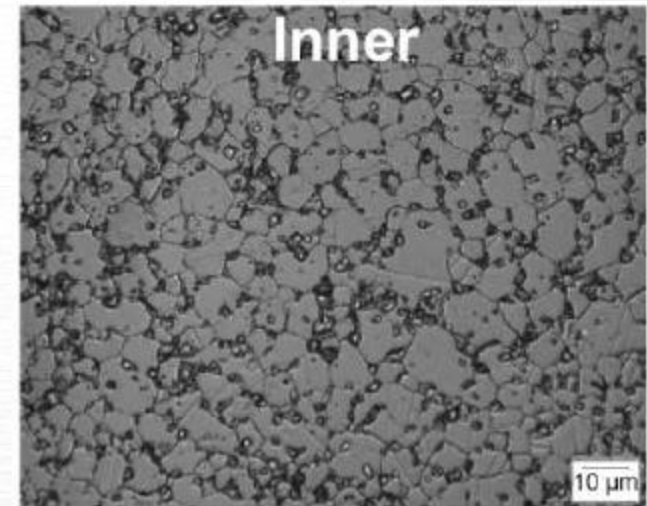
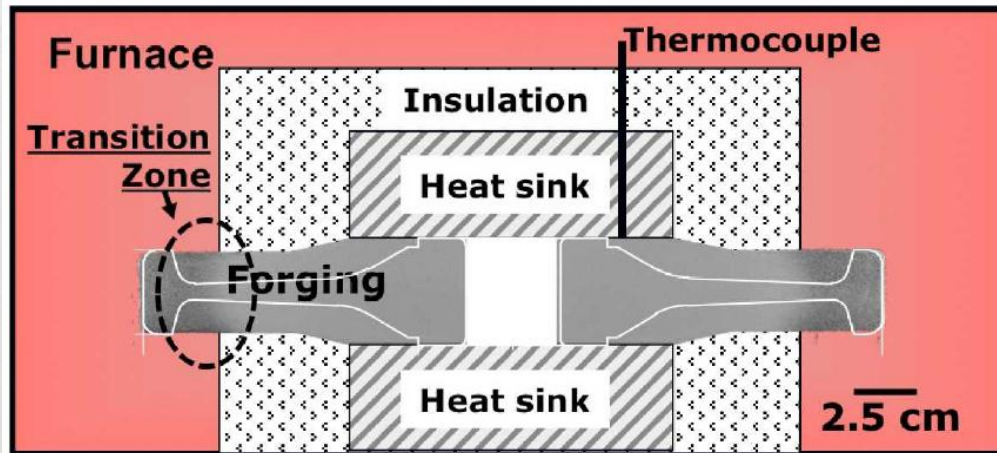


From Gabb, 2003-212086



From Jian Mao, WVU

Several Dual Grain Size Processes Exist



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Flight Cycles Impact Material Needs

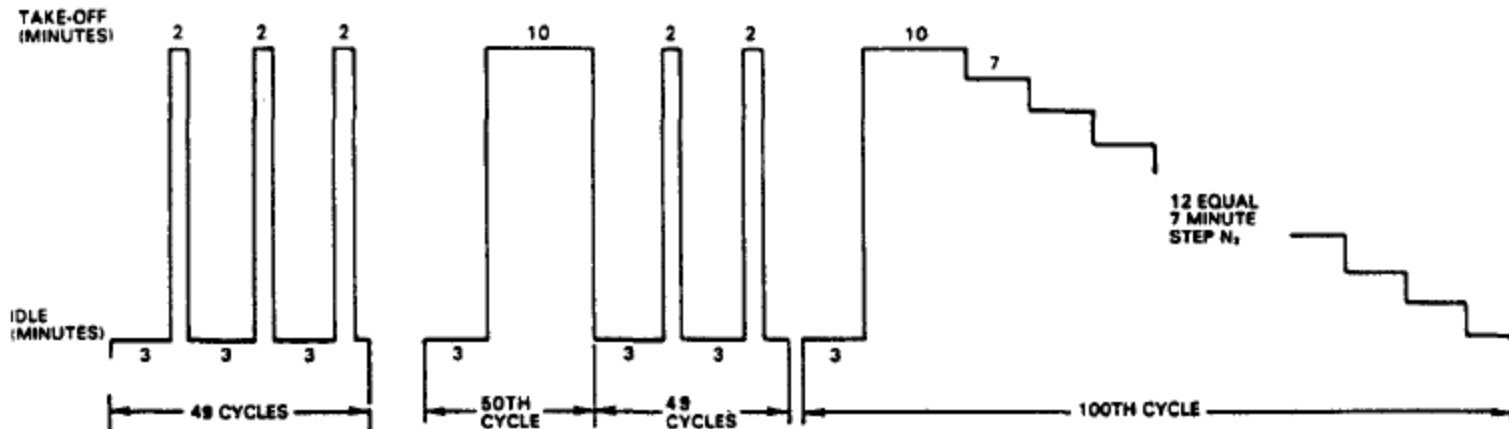


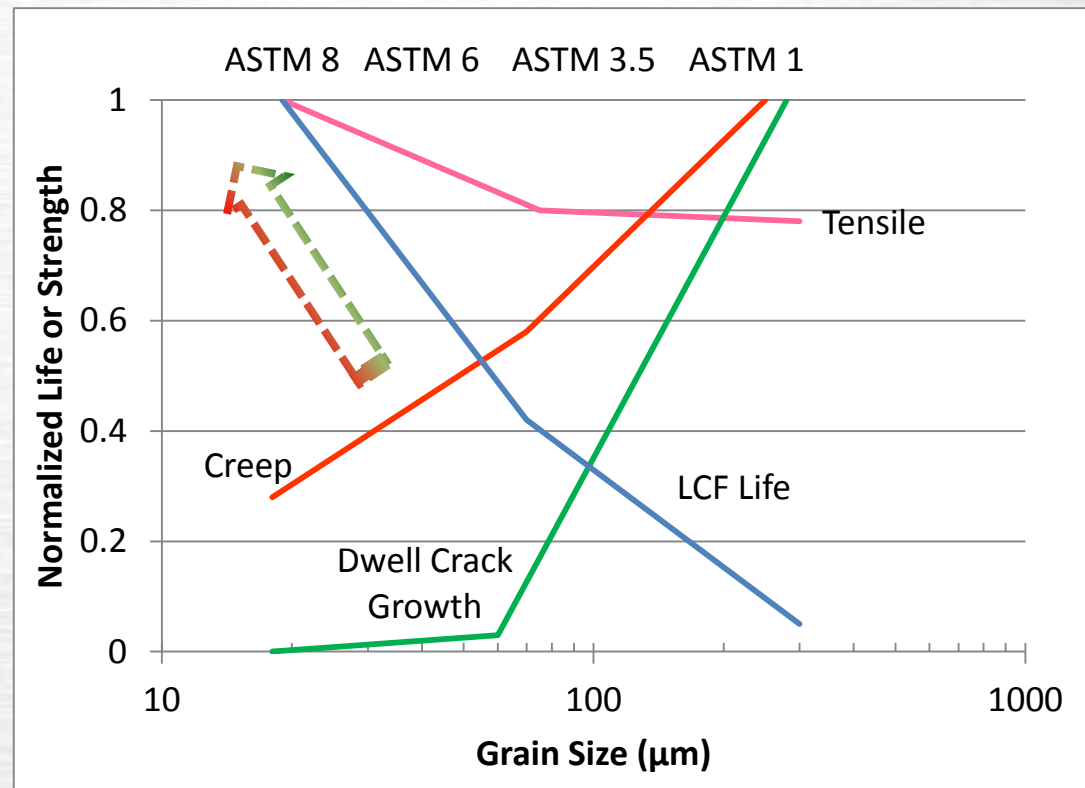
Figure 4 Schematic of JT9D Experimental Test Engine Cycle, Showing 100 Cycles of 150 Hour/ 1500 Cycle Endurance Test

1982 NASA CR-165550

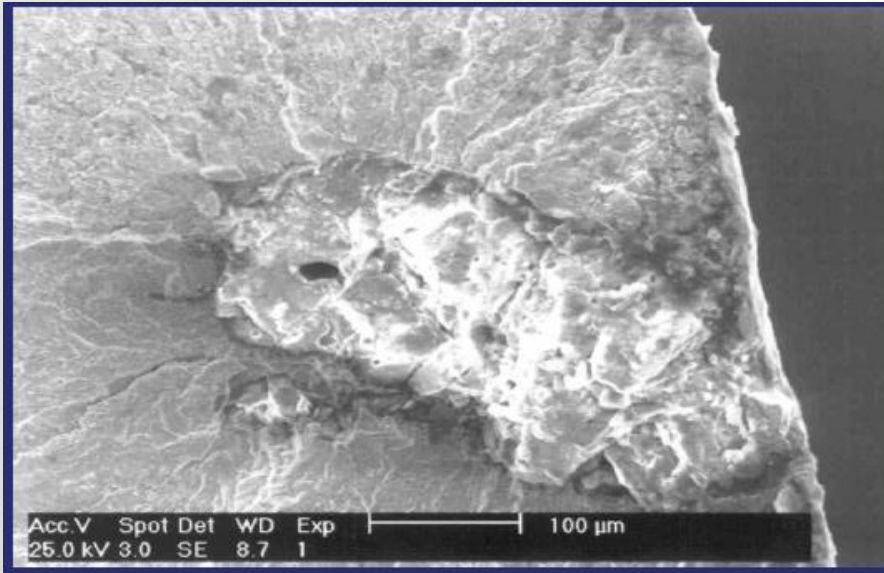
Peak loading cycles have increased from relatively short peak cycle loads of 2 – 10 minutes to 20 minutes as fuel and flight efficiencies increase as well as environmental concerns are addressed.

Advancing the Current Alloys System

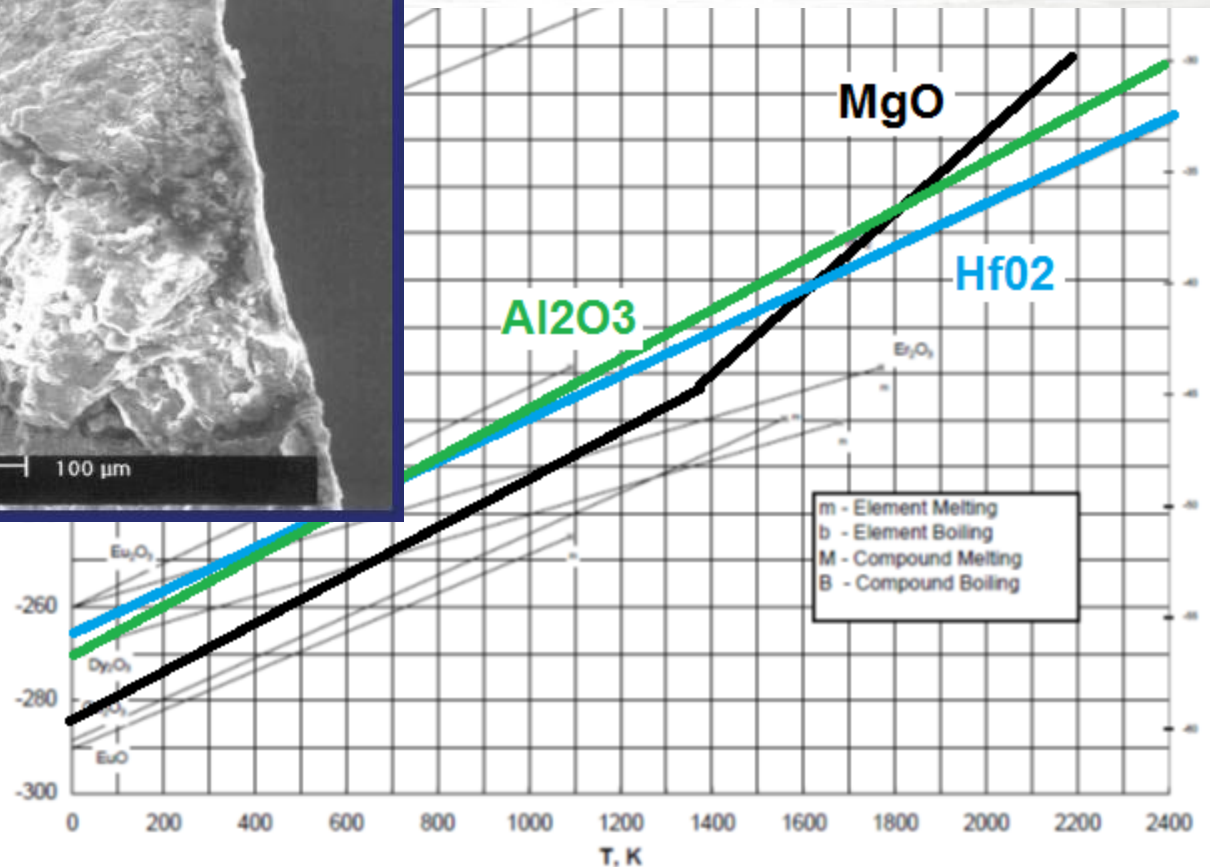
One trend in current alloy systems concerns balancing the solid solution strengtheners for creep resistance and oxidation resistance at the crack front while avoiding detrimental TCP phases.



Control of Refractory Type Elements



Hicks– Rolls Royce



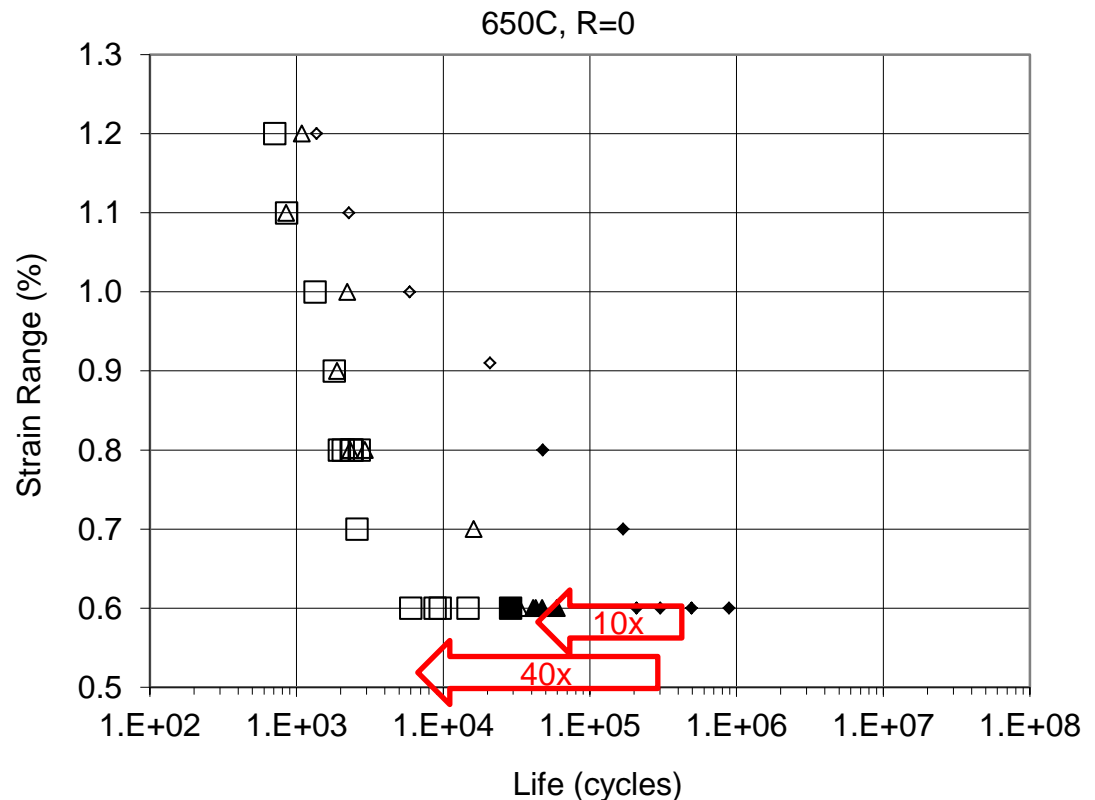
Ellingham Diagram for Selected Oxides: Part-2

Data from Thomas B. Reed, Free Energy of Formation of Binary Compounds, MIT Press, Cambridge, MA, 1971.

© 2008 Stanley M. Howard

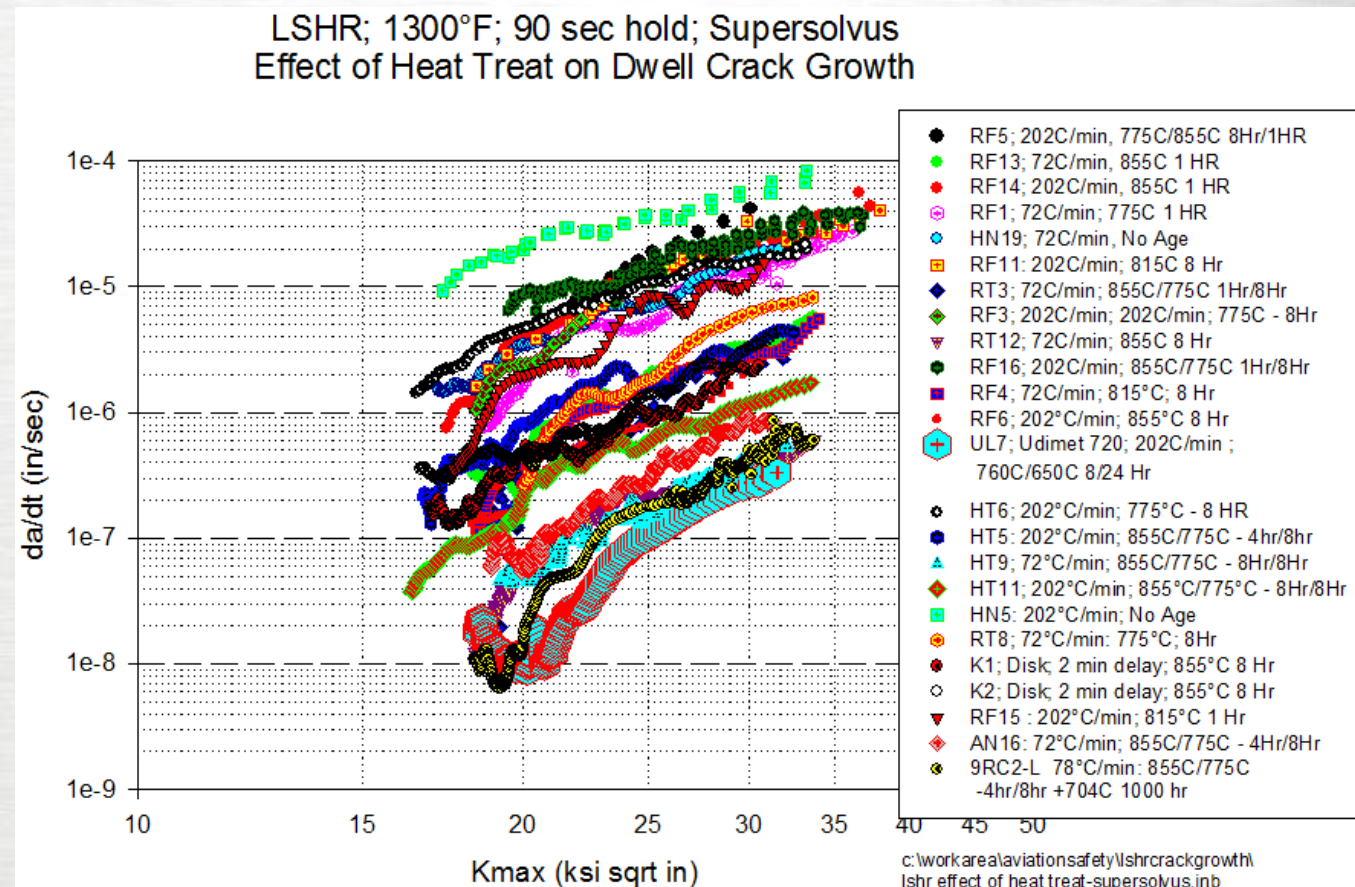
Critical Inclusion Size and Frequency

- Increased size and content of these inclusions can lower PM fatigue life, especially in situations where they intersect a stressed disk surface
- PM material has been seeded with extra inclusions to quantify these effects

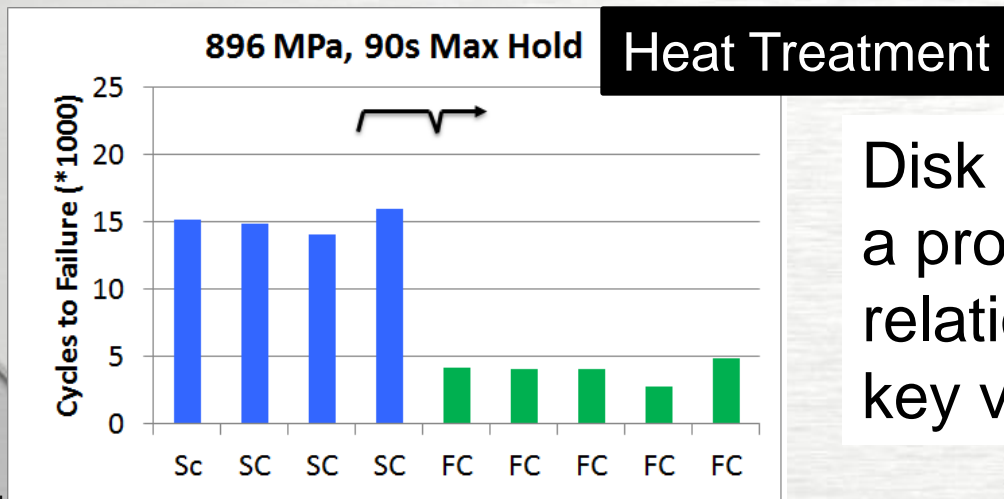
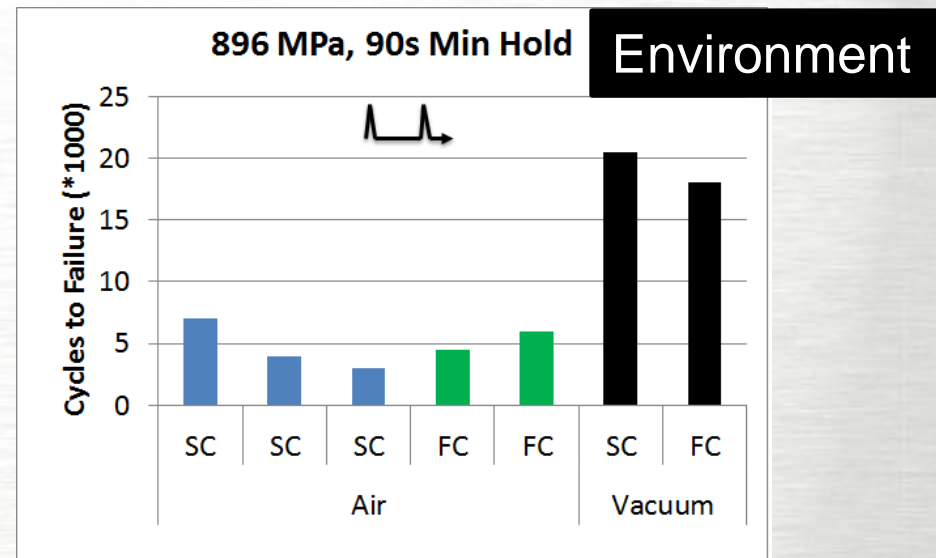
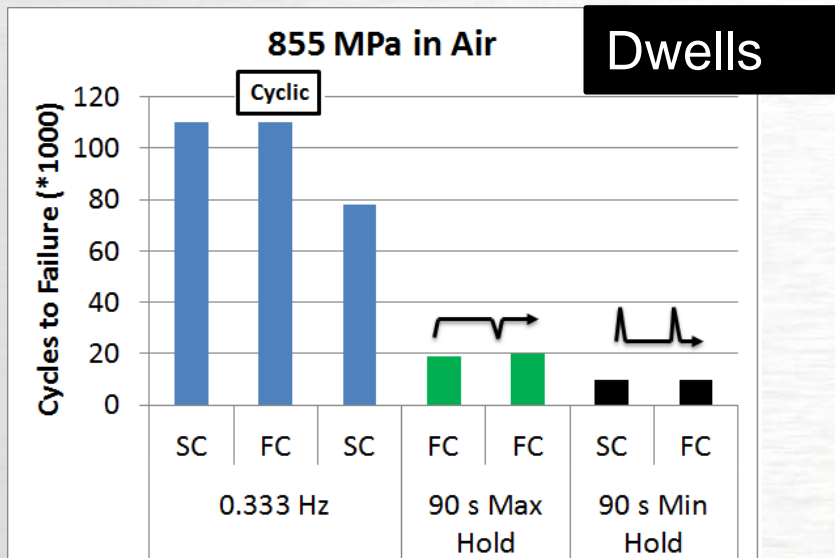


Hold Time Crack Growth

- Hold time crack growth in air can be influenced with heat treatment
- However, heat treatments must attain a balance of numerous mechanical properties



Notch Fatigue Life Behavior



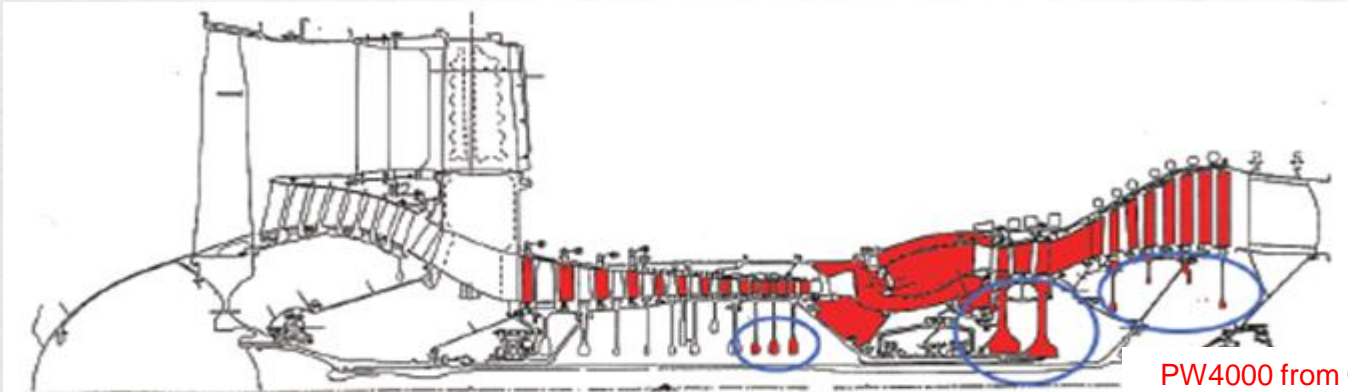
ME3 – Telesman, Seven Springs 2012

Disk alloy fatigue behavior is a product of a complex inter-relationship of a number of key variables.

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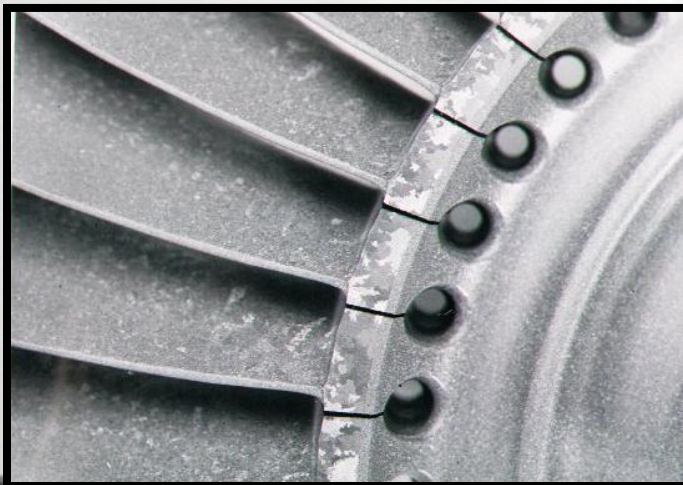
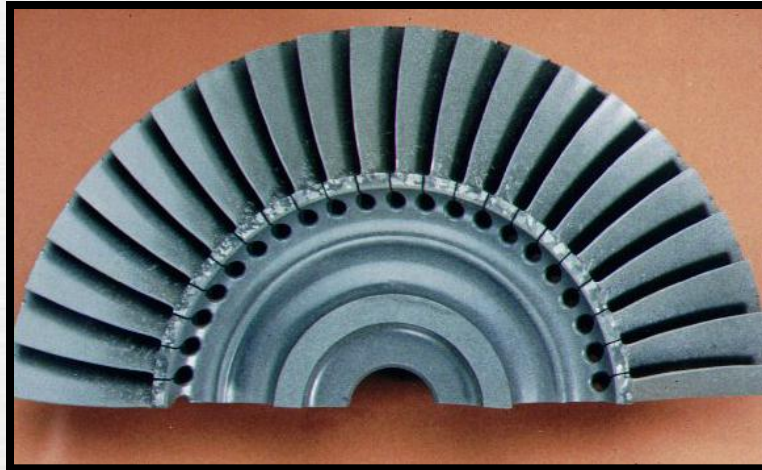
Composition-Property Tailoring



PW4000 from ONERA paper

	Cr	Co	Ti	Al	Mo	C	V	B	Zr	Ni	Ta	W	Nb	Hf	Re
Oxidation Resistance	+						+			+					
Creep Resistance	-				+							+	+	+	+
Fatigue Resistance	+				-							-			
Solid Solution Strengthenener					+							+			
Phase Stability	-												-		
Gamma Prime Strengthenener			+	+							+				
Reduced Density			+	+	-						-	-			
Powder Processing															
Increased Process Window		+	-	-		+		+		+	-				
Heat Treat Stability			-	-					+						
Increased Ductility for Burst					-				+			-			

Dual Alloy HP Turbine Disk



Calibrated Models Will Provide Opportunities

